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DRYING SHRINKAGE IN CONCRETE USING RECYCLED AGGREGATE FROM CONSTRUCTION AND DEMOLITION WASTE

NGUYEN ANH DUC*, NGUYEN PHAN ANH, NGO VIET ANH
Faculty of Civil Engineering, Vietnam Maritime University
**Corresponding email: ducna.ctt@vimaru.edu.vn*
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Abstract

In Vietnam, rapid urbanization and infrastructure development make a critical increase in construction and demolition waste (CDW), posing many environmental challenges. CDW also occupies a large area of landfills causing many problems for populous residence. A promising sustainable solution is recycling CDW into recycled aggregates in concrete production. However, the properties of recycled aggregates raise concerns about the long-term performance especially drying shrinkage. This study investigates the effect of recycled aggregates produced from CDW to the drying shrinkage in concrete.

Concrete mixtures with varying replacement ratios of recycled aggregates in concrete were designed and specimens were prepared. After 26 weeks, the results showed a clear correlation between the recycled aggregates replacement ratio and drying shrinkage. Mixtures with higher replacement ratio of recycled aggregates show a significantly increased drying shrinkage compared to normal concrete. The results of this research addressed the necessity for mix proportion design adjustments for recycled aggregate concrete to mitigate drying shrinkage and facilitate its reliable, high-volume application in Vietnam, which can promote a sustainable development for construction industry.

Keywords: *Drying shrinkage, recycled aggregate concrete, construction and demolition waste.*

1. Introduction

According to the Mineral Commodity Summaries 2025 of United States Geological Survey, Vietnam ranked as the world's third-largest cement producer, with an annual output of 110 million tons [1]. This significant level of production underscores a correspondingly high demand for construction which uses a huge amount of materials such as natural stone and sand. A prior investigation highlighted a substantial deficit in the supply of sand within the country. The annual demand for sand used in mortar and concrete was estimated at approximately 120 million cubic meters, yet domestic supply could meet only 24.2% of this requirement [2]. Furthermore, the demand for sand for land-filling and leveling purposes was considerably higher, reaching around 575 million cubic meters, in which 1.5% of this demand being met domestically.

Furthermore, rapid urbanization and infrastructure development make a critical increase in construction and demolition waste (CDW), posing many environmental challenges. CDW also occupies a large area of landfills causing many problems for populous residence. In this situation, a solution to recycle CDW as aggregates in concrete is a promise countermeasure to solve the above problems. However, in Vietnam, CDW is include a large amount of brick which can be up to 31% [3]. Further, after crushing CDW to produce recyceld aggregates, the adhered mortar on the surface of these aggregates can affect the quality because of high water absorption and lower density [4]. These properties can affect the durability of recycled aggregate concrete (RAC) especially drying shrinkage.

Drying shrinkage occurs in concrete when the changes in chemical content or moisture content causing the length change or volume change. Especially for RAC, with a large amount of adhered mortar on the recyceld aggregates, the porosity and water absorption are high. As a result, the loss of moisture content in recyceld aggregates following times can cause drying shrinkage bigger than normal concrete that only using natural aggregate [5].

In this research, concrete mixtures with varying replacement ratios of recycled aggregates in concrete were designed and specimens were prepared. After 26 weeks, the results showed a clear correlation between the recycled aggregates replacement ratio and drying shrinkage. Mixtures with higher replacement ratio of recycled aggregates show a significantly increased drying shrinkage compared to normal concrete. By using the forecast equation of drying shrinkage at 26 weeks can be estimated based on the results of 1, 4, 8, and 13 weeks. The results addressed the necessity for mix proportion design adjustments for recycled aggregate concrete to mitigate drying shrinkage and facilitate its reliable, high-volume application in Vietnam, which can promote a sustainable development for construction industry.

2. Materials

2.1. Portland Cement

Portland cement (PC) was used in this study as binder in mix proportion. Properties of PC are shown in Table 1.

Table 1. Properties of Portland Cement (PC)

Item	Unit	OPC
Density	*g/cm^3*	3.16
Loss on Ignition	*%*	3.52
SO_3	*%*	2.02

2.2. Aggregate

The recycled aggregates were processed using an impact crusher and subsequently graded through sieving. Table 2 presents the properties of the aggregates. The natural aggregates consisted of natural crushed stone (CA) (05-20 mm) and natural river sand (RS) (0-5 mm). The recycled coarse aggregate (RCA) has a water absorption of 5.68% and an density in oven-dry condition of 2.41g/cm^3. According to the Vietnamese standard TCVN 11969:2018 for recycled coarse aggregate in concrete, this RCA is classified as Type II. Meanwhile, the recycled fine aggregate (RFA) demonstrated a higher water absorption of 8.47% and a density in oven-dry condition of 2.27g/cm^3, which corresponds to the

Table 2. Properties of aggregate

Item	Unit	CA[1]	RS[2]	RCA[3]	RFA[4]
Density in water saturated condition	*g/cm^3*	2.68	2.66	2.55	2.46
Density in oven-dry condition	*g/cm^3*	2.65	2.62	2.41	2.27
Water absorption	*%*	1.16	1.47	5.68	8.47
Fineness modulus	-	6.62	2.57	6.59	3.68
Content of materials finer than 75 μm	*%*	1.1	2.7	1.2	5.0
Amount of contained impurities	*%*	-	-	0.06	0.00

1 CA: coarse aggregate, 2 RS: fine aggregate (river sand), 3 RCA: recycled coarse aggregate, 4 RFA: Recycle fine aggregate

Table 3. Mix Proportion

Specimen[1]	Replacement ratio (%)		Unit weight[2] (kg/m^3)						Qat[3] (%)
	RCA	RFA	W	PC	CA	RS	RCA	RFA	
NC	0	0	180	327	965	807	0	0	1.30
CA100-RFA50	0	50	180	327	965	403	0	350	2.91
CA100-RFA100	0	100	180.	327	965	0	0	699	4.51
RCA50-RS100	50	0	180	327	482	807	439	0	2.53
RCA50-RFA30	50	30	180	327	466	586	424	218	3.49
RCA100-RS100	100	0	180	327	0	807	877	0	3.75

1 Specimens have W/C = 55% and named as type and replacement ratio of aggregate, the number on the right side is replacement ratio, for example: CA100-RFA50 means 100% coarse aggregate and 50% recycle fine aggregate were used, RCA50-RFA30 means 50% recycled coarse aggregate and 30% recycled fine aggregate were used in mix proportion. All specimens used water reducing admixture from Naphthalene formaldehyde sunfonate equal to 1%

Class L for recycled aggregate regulated in the Japanese industrial standard JIS A 5023:2018.

3. Mix proportion

Table 3 outlines the mix proportions in this research. A constant water-to-cement ratio (W/C) of 55% was chosen for all mixtures, which incorporated a water-reducing admixture at a dosage of 1% by mass of the PC.

Following preliminary testing, the unit weight of water was established at 180kg/m^3 to achieve the target slump of 18±2.5 cm. The normal concrete using PC40 cement and 100% natural aggregates. The remaining mixes used recycled coarse aggregates at replacement ratio of 50% and 100%. Recycled fine aggregates were used at the replacement ratio of 30%, 50%, and 100%. For each successful concrete batch, three specimens were cast per mix proportion to assess drying shrinkage. All testing apparatus was used in accordance with the manufacturers' standard configurations, without additional calibration.

An relative quality index was applied to assess the correlation between concrete performance and the relative water absorption (Qat) of the mix proportion [8]. Based on the mix proportions, the Qat was calculated as a weighted average using Equation (1) using water absorption and absolute volume of aggregates in mix proportions. The results are shown in Table 3. This index was subsequently used to evaluate its relationship with the drying shrinkage of the concrete in this research.

$$Qat = \frac{Q_{aCA} \times V_{CA} + Q_{aRS} \times V_{RS} + Q_{aRCA} \times V_{RCA} + Q_{aRFA} \times V_{RFA}}{V_{CA} + V_{RS} + V_{RCA} + V_{RFA}} \quad (1)$$

In which,

Qat: Relative water absorption (%);

Q_{aCA}: Water absorption of normal coarse aggregate (%);

Q_{aRS}: Water absorption of normal fine aggregate (%);

Q_{aRCA}: Water absorption of recycled coarse aggregate (%);

Q_{aRFA}: Water absorption of recycled fine aggregate (%);

V_{CA}, V_{RS}, V_{RCA}, V_{RFA}: Absolute volume of the aggregates (L/m^3).

4. Results and discussion

4.1. Properties of fresh concrete

The slump of fresh concrete was measured in accordance with the Vietnamese standard TCVN 3106:2022. The unit weight and temperature of the fresh mixtures were determined following TCVN 3108:1993 and TCVN 9340:2012, respectively. The results for the fresh properties are summarized in Table 4. All concrete mixtures achieved the target slump of 18±2.5 cm. Compared to the normal concrete (NC), concrete specimens using recyceld aggregates had lower slump due to the shape of the aggregate [6].

Table 4. Experiment results of fresh concrete

Item	Slump (cm)	Density (kg/m^3)	Temperature (°C)
NC	19.0	2336	28.4
CA100-RFA50	18.5	2234	28.5
CA100-RFA100	18.0	2084	28.1
RCA50-RS100	17.5	2273	27.3
RCA50-RFA30	18.5	2247	26.1
RCA100-RS100	17.5	2208	27.7

A clear inverse correlation was observed between the recycled aggregate's replacement ratio and the density of the concrete. Compared with the case of normal concrete, specimens incorporating 100% RCA and those with 100% RFA exhibited the most significant reduction in density, demonstrating this trend conclusively. This trend is due to the amount of low-density adhered mortar on the surface of recycled aggregates [7].

The measured temperature of the fresh concrete across all specimens ranged from 26.1°C to 28.5°C.

4.2. Drying shrinkage of hardened concrete

For the evaluation of drying shrinkage, three specimens (100mm × 100mm × 400mm) for each mix proportion were prepared. The mean result from these triplicate specimens was adopted for analysis. The specimens designated for drying shrinkage measurement were initially cured in environment at 20 ± 2°C and moisture content of ≥ 95%. Following demolding, these specimens had standard curing until reaching 7-day of age, after which they were transferred to a controlled climate chamber maintained at 20 ± 2°C and 60 ± 5% relative humidity (RH) for the remainder of the measurement period of

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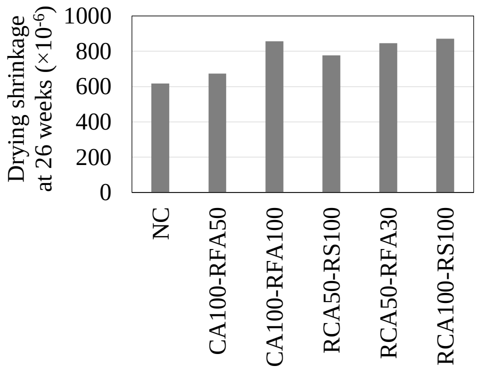

Figure 1. Drying shrinkage of concrete specimens at 26 weeks (×10^{-6})

1 week, 4 weeks, 8 weeks, 13 weeks and 26 weeks following Japanese Architectural Standard Specification (JASS 5) [8]. This condition is monitored and maintained by the same equipments which has temperature sensor and moisture sensor, these sensors can assure environmetal conditions in chamber always at 20 ± 2°C and 60 ± 5% RH. Drying shrinkage measurement was conducted accordance with Japanese Industrial Standard JIS A 1129-3.

Figure 1 shows the results of drying shrinkage of concrete specimens at 26 weeks which are the most important value to evaluate this performance of concrete according to JASS 5 [8]. Drying shrinkage is bigger when the replacement ratio of recycled aggregates such as RCA and RFA increased. Especially in the case of 100% RCA and 100% RFA were used, drying shrinkage is significantly increased. This trend is also observed in the research of Wang et. al. [9]. This trend is due to the adhered mortar on the surface of recycled aggregates which has high porosity and make water absorption higher [10, 11]. Since TCVN 3117:2022 is not regulate the range for drying shrinkage in concrete, the values in Vietnam standards 22TCN 60-84, 1×10^{-4} to 15×10^{-4} µm/m of drying shrinkage for normal concrete can be used to compared with experiment result. Based on this regulated range, even high replacement ratio of recycled aggregates causing significant increase of drying shrinkage, all specimens still meet the requirement.

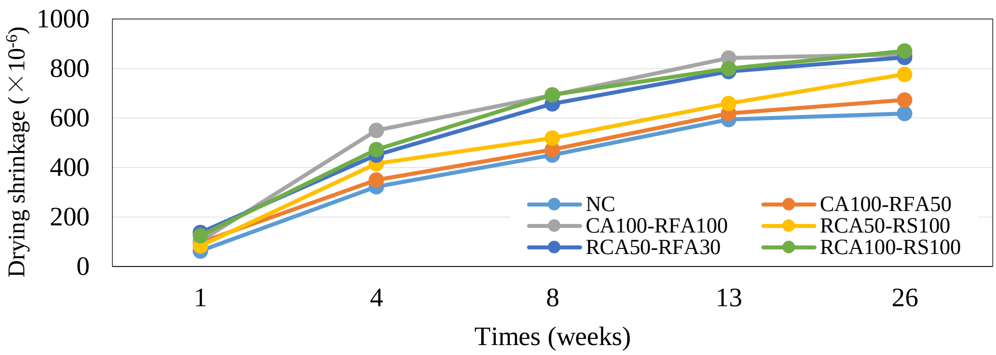

Figure 2. Drying shrinkage of concrete specimens from 1 week to 26 weeks

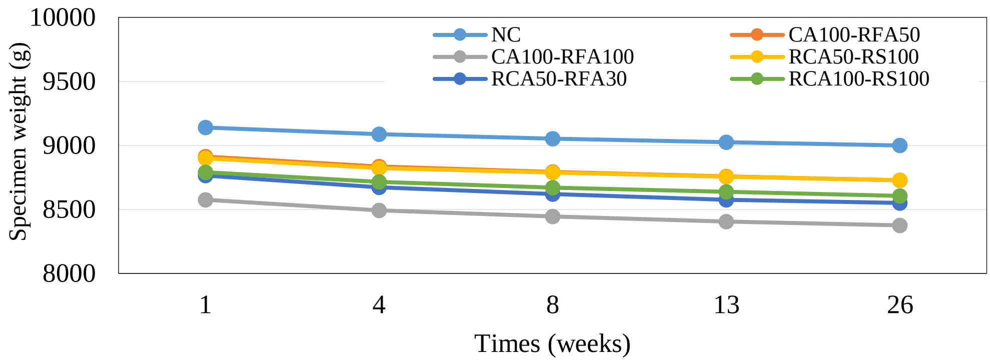

Figure 3. Weight loss of concrete specimens from 1 week to 26 weeks

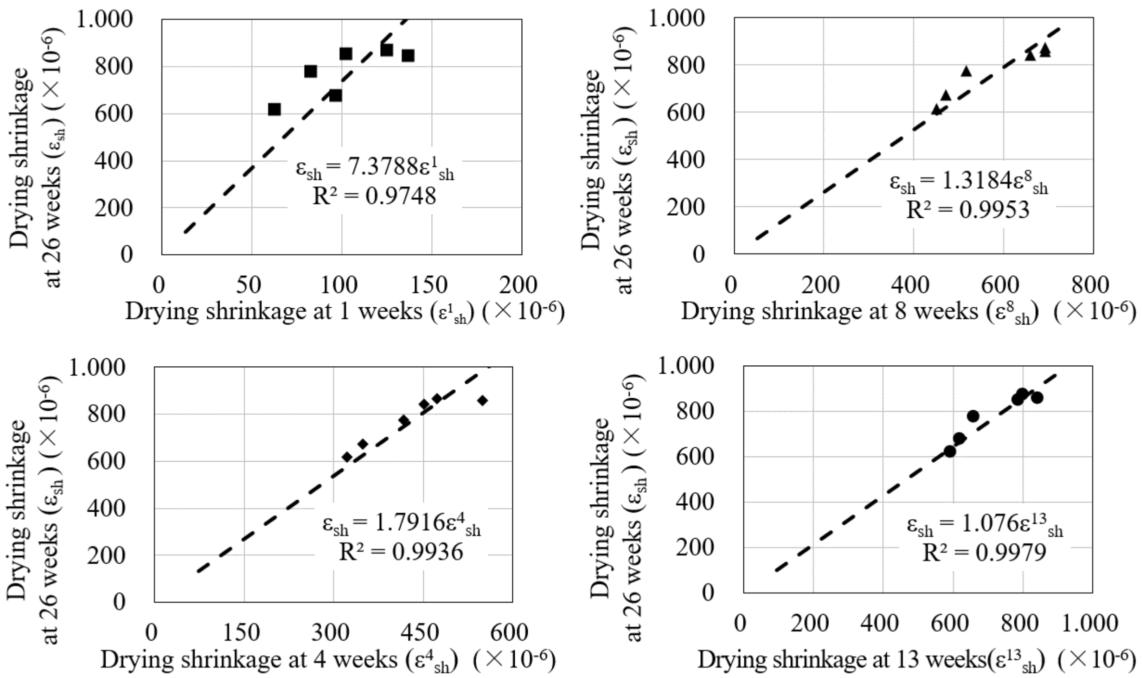

Figure 4. Forecast equation of drying shrinkage at 26 weeks

The significant loss of water in recycled aggregate concrete specimens causes drying shrinkage rapidly increased and specimens weight decreased when comparing to the normal concrete specimen (NC) [12] which can be clearly observed in Figure 2 and Figure 3 for concrete specimens from the age of 1 week to 26 weeks. This trend is also reported in the research of Zhang et al. in 2022 [13].

Some researchers also forecast the drying shrinkage of recycled aggregate concrete [14, 15]. According to JASS 5, based on the experiment results, equations can be proposed to forecast the drying shrinkage of similar types of concretes [8]. These equations can be achieved by analyzing the experiments results from 1 week to 13 weeks and the experiments results at 26 weeks to get the correlations between them. After analyzing the experimental results, this research proposed Equations (2), (3), (4), and (5) as the forecast equations for estimating the drying shrinkage at 26 weeks of recycled aggregate concrete which is shown in Figure 4.

$$\varepsilon^{est}_{sh}=7.3788 \times \varepsilon^{1}_{sh} \quad (2)$$

$$\varepsilon^{est}_{sh}=1.7916 \times \varepsilon^{4}_{sh} \quad (3)$$

$$\varepsilon^{est}_{sh}=1.3184 \times \varepsilon^{8}_{sh} \quad (4)$$

$$\varepsilon^{est}_{sh}=1.0763 \times \varepsilon^{13}_{sh} \quad (5)$$

In which,

ε^{est}_{sh}: Estimated drying shrinkage at 26 weeks (×10^{-6});

ε^{1}_{sh}: Drying shrinkage at 1 week (×10^{-6});

ε^{4}_{sh}: Drying shrinkage at 4 weeks (×10^{-6});

ε^{8}_{sh}: Drying shrinkage at 8 weeks (×10^{-6});

ε^{13}_{sh}: Drying shrinkage at 26 weeks (×10^{-6}).

Further, Figure 5 shows the relationship between relative water absorption calculated by Equation (1) and experimental results of drying shrinkage at 26 weeks. A clear correlation can be observed. The higher the relative water absorption, the bigger drying shrinkage can be [16]. As a result, when replacement

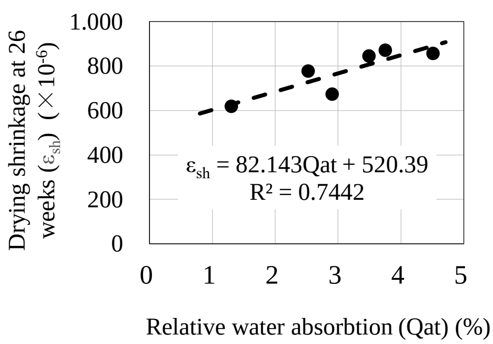

Figure 5. Relationship between relative water absorption (Qat) with drying shrinkage at 26 weeks

ratio of recycled aggregates is high, drying shrinkage must be considered to not exceed the required range in 22TCN 60-84. Based on this relative quality index method, with the proposed equation in Figure 5, a mix proportion of recyled aggregate concrete can be designed with a target drying shrinkage. Further, other performances of concrete will be evaluated in the next phase of the research.

5. Conclusion

This study evaluates the drying shrinkage of concrete using recycled aggregates. The research aims to facilitate the broader adoption of this sustainable practice in Vietnam, aligning with global initiatives for resource recycling orient to a sustainable development of construction industry.

Drying shrinkage is bigger when the replacement ratio of recycled aggregates increases. Especially in the case of 100% RCA and 100% RFA were used, drying shrinkage is significantly increased.

By analyzing the experimental results, this research proposed the forecast equations for estimating the drying shrinkage at 26 weeks of recycled aggregate concretes based on the experimental results of 1, 4, 8, and 13 weeks.

For relative quality index method, A clear correlation can be observed beetween relative water absorption and drying shrinkage. Based on this relative quality index method, a mix proportion of recyled aggregate concrete can be designed with a target drying shrinkage.

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